



US008062948B2

(12) **United States Patent**
Shin

(10) **Patent No.:** **US 8,062,948 B2**
(45) **Date of Patent:** **Nov. 22, 2011**

(54) **METHOD OF FABRICATING TRANSISTOR
FOR SEMICONDUCTOR DEVICE**

(75) Inventor: **Min-Jung Shin**, Gyeonggi-do (KR)

(73) Assignee: **Hynix Semiconductor Inc.**,
Gyeonggi-do (KR)

(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 0 days.

(21) Appl. No.: **12/492,939**

(22) Filed: **Jun. 26, 2009**

(65) **Prior Publication Data**

US 2010/0167486 A1 Jul. 1, 2010

(30) **Foreign Application Priority Data**

Dec. 29, 2008 (KR) 10-2008-0135584

(51) **Int. Cl.**
H01L 21/336 (2006.01)

(52) **U.S. Cl.** **438/300**; 438/413; 257/E21.431

(58) **Field of Classification Search** 257/190,
257/288, 304, 368, 369, E21.431; 438/233,
438/299, 300, 413

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,670,923 B1 * 3/2010 Nayak et al. 438/413

2010/0099231 A1 * 4/2010 Siprak 438/299

FOREIGN PATENT DOCUMENTS

KR 101998040751 8/1998
KR 100834740 6/2008

OTHER PUBLICATIONS

Notice of Preliminary Rejection issued from Korean Intellectual
Property Office on Nov. 3, 2010.

Notice of Preliminary Rejection issued from Korean Intellectual
Property Office on Aug. 26, 2011.

* cited by examiner

Primary Examiner — Thanh V Pham

Assistant Examiner — Errol Fernandes

(74) *Attorney, Agent, or Firm* — IP & T Group LLP

(57) **ABSTRACT**

A method of fabricating a transistor in a semiconductor device includes forming a gate structure over a substrate, forming a first trench by etching the substrate on either side of the gate structure to a first depth, ion-implanting dopants of a first conductivity type to form a source/drain region in the substrate on the side of the gate structure with the first trench, etching the substrate on the side of the gate structure with the first trench to a second depth larger than the first depth to form a second trench, and growing an epitaxial layer within the second trench.

9 Claims, 7 Drawing Sheets

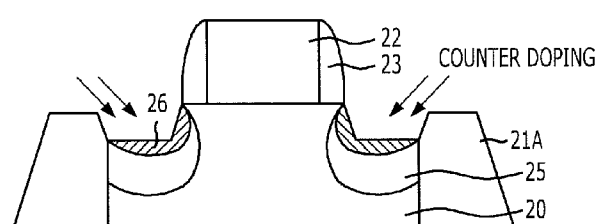
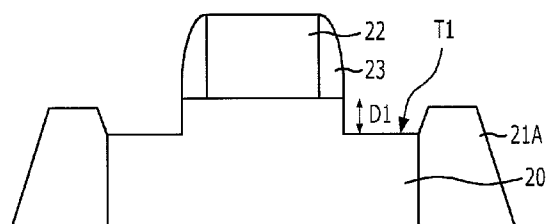


FIG. 1A
(PRIOR ART)

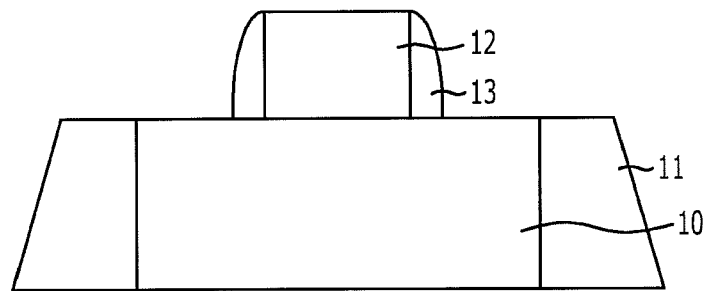


FIG. 1B
(PRIOR ART)

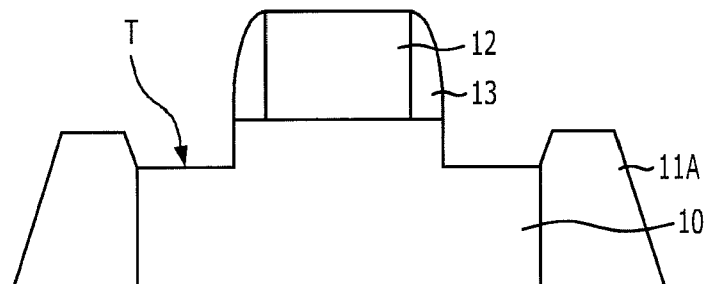


FIG. 1C
(PRIOR ART)

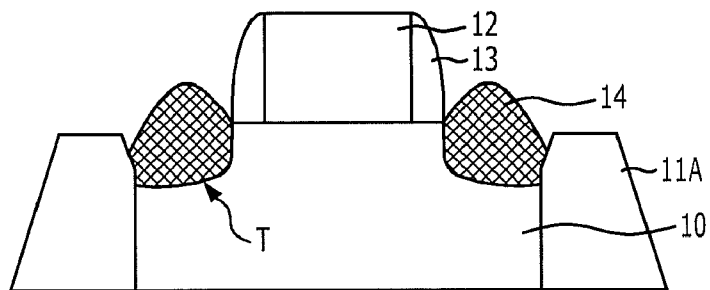


FIG. 1D
(PRIOR ART)

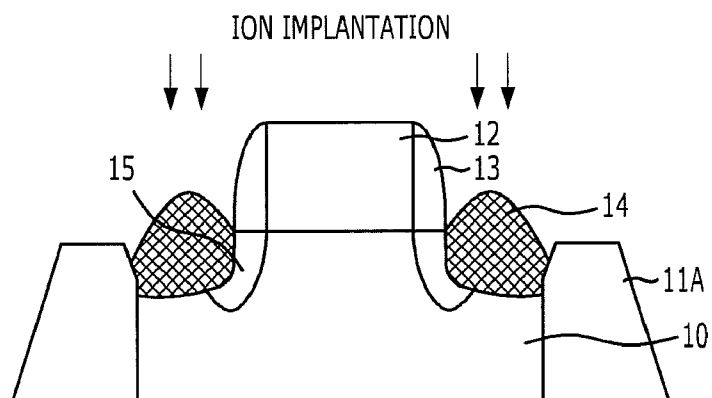


FIG. 1E
(PRIOR ART)

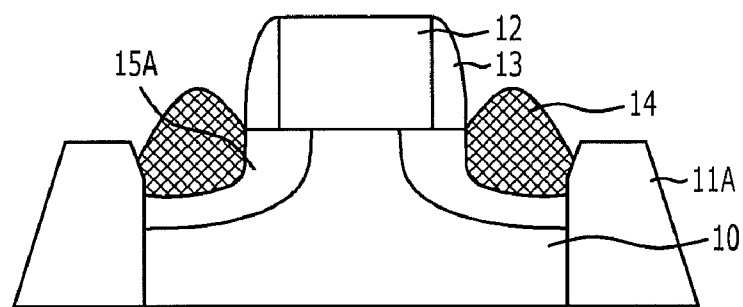


FIG. 2A

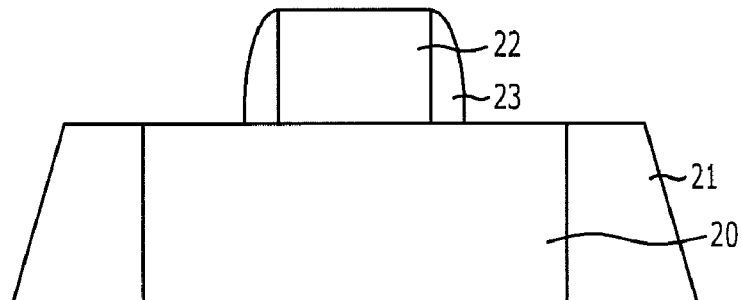


FIG. 2B

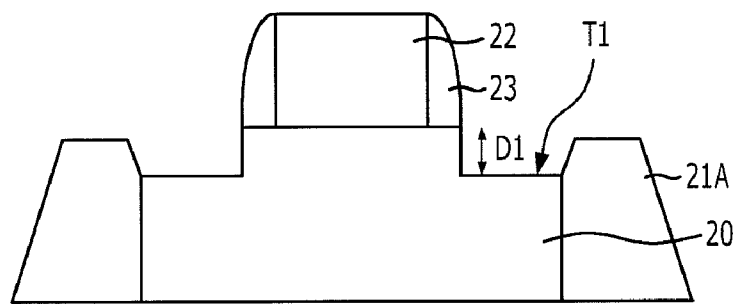


FIG. 2C

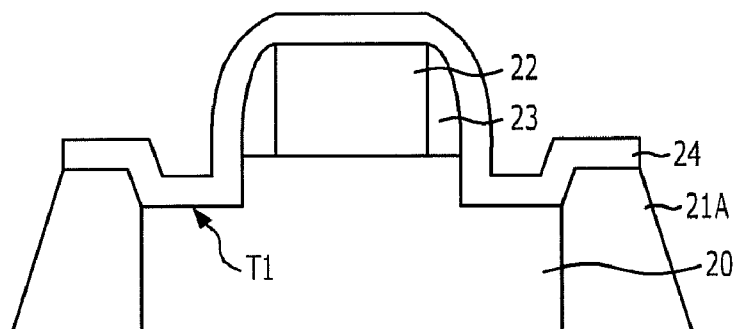


FIG. 2D

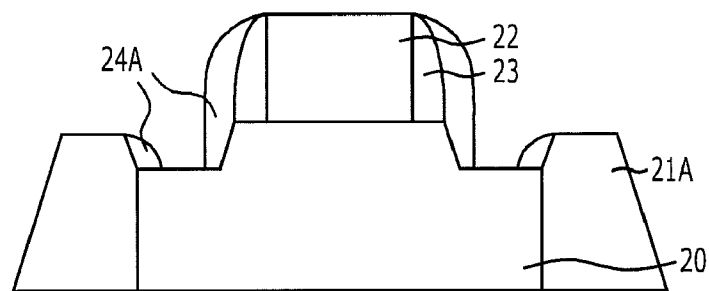


FIG. 2E

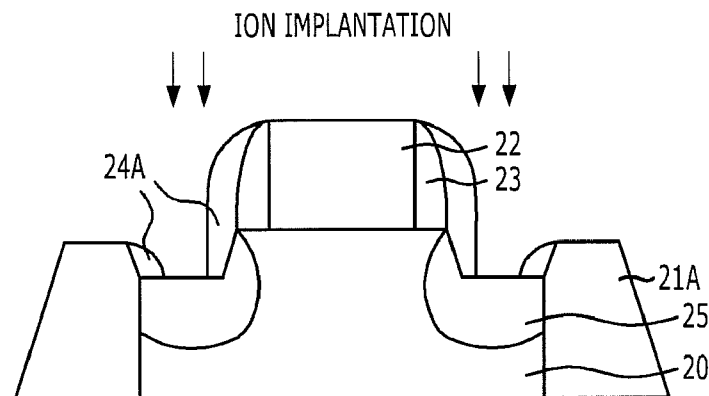


FIG. 2F

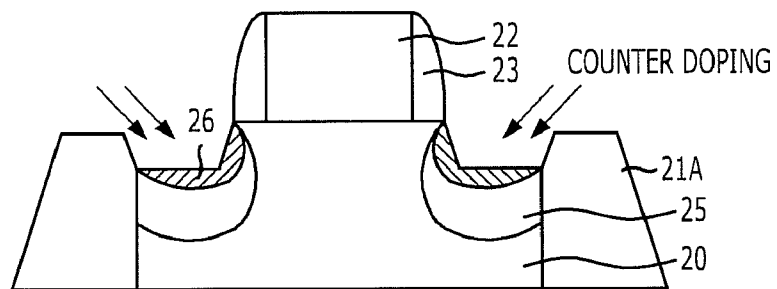


FIG. 2G

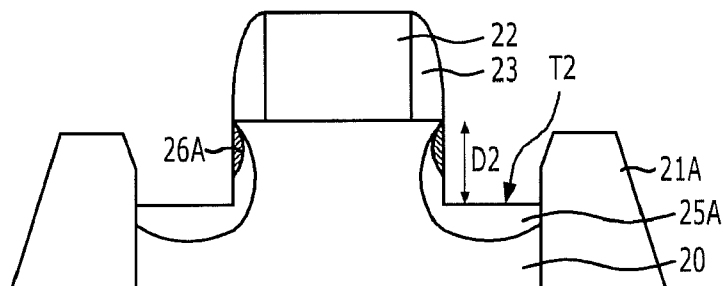
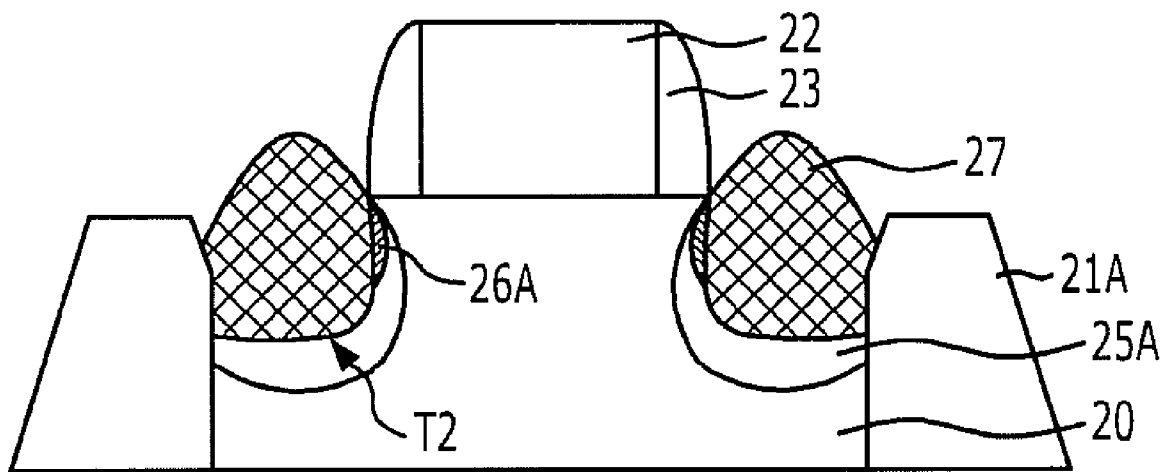


FIG. 2H



1

METHOD OF FABRICATING TRANSISTOR FOR SEMICONDUCTOR DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

The present invention claims priority of Korean patent application number 10-2008-0135584, filed on Dec. 29, 2008, the disclosure of which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

The present invention relates to a semiconductor fabrication technology, and more particularly, to a method of fabricating a transistor for use in a semiconductor device.

As semiconductor devices are being highly integrated, one of important issues is to fabricate transistors that can ensure a high current drivability and a short channel margin even at small dimensions.

Recently, extensive studies have been conducted to increase carrier mobility in order to ensure a high current drivability. Carrier mobility may be increased by applying a certain stress to a channel region defined under a gate, leading to improving current characteristic of transistors. To this end, various transistor structures and fabrication methods thereof have been proposed, and one such example is illustrated in FIGS. 1A to 1D.

FIGS. 1A to 1D are cross-sectional views explaining a structure of a conventional PMOS transistor and a fabrication method thereof.

Referring to FIG. 1A, a device isolation layer **11** is formed on a substrate **10** to define an active region.

A gate pattern **12** having a stacked structure of a gate insulation layer, a gate electrode and a gate hard mask is formed on the substrate **10**, and a gate spacer **13** is formed on a sidewall of the gate pattern **12**.

Referring to FIG. 1B, the substrate **10** on either side of the gate spacer **13** is etched to a certain depth to form a trench T. Reference numeral **11A** represents an etched device isolation layer.

Referring to FIG. 1C, an epitaxial layer **14** is grown within the trench T by using a sidewall and/or bottom of the trench T as a seed layer.

The epitaxial layer **14** is used to apply a stress to the channel region of the substrate **10**. In the case of the PMOS transistor, a compression stress is applied in a direction parallel to the channel region in order to increase the mobility of majority carriers, i.e., holes. Thus, the epitaxial layer **14** is formed of a material having a larger lattice constant than the substrate **10**. For example, when the substrate **10** is a Si substrate, the epitaxial layer **14** may be a SiGe epitaxial layer.

Referring to FIG. 1D, an initial source/drain region **15** is formed by ion implantation of P-type dopants such as boron (B).

Referring to FIG. 1E, a thermal treatment is performed for dopant activation. As a result, the dopants are diffused to form a final source/drain region **15A**. In this manner, a PMOS transistor having a structure of FIG. 1E is completed.

However, there are the following limitations on the structure of the conventional PMOS transistor and the fabrication method thereof.

When the epitaxial layer **14** such as SiGe is grown, it is grown not uniformly but in a convex shape (see FIGS. 1C to 1E). Due to the shape of the epitaxial layer **14**, the dopants for forming the source/drain region in a subsequent process are relatively more ion-implanted into edges of the gate pattern

2

12 than other positions (see FIG. 1D). From the profile of the final source/drain region **15A** when the dopants are diffused by the subsequent thermal treatment, it can be seen that lateral diffusion of the dopants is so active that the side of the final source/drain region **15A** penetrates even under the gate pattern **12**, whereas the bottom of the final source/drain region **15A** is relatively shallow.

If the side of the final source/drain region **15A** penetrates even under the gate pattern **12**, the short channel margin of the transistor is degraded and, in particular, Drain Induced Barrier Lowering (DIBL) is degraded.

Furthermore, if the bottom of the final source/drain region **15A** is shallow, leakage current characteristic is degraded due to interface defect between the substrate **10** and the epitaxial layer **14**.

Therefore, there is a need for a method of fabricating a new transistor capable of solving the above-mentioned limitations.

SUMMARY OF THE INVENTION

Embodiments of the present invention are directed to providing a method of fabricating a transistor for use in a semiconductor device. In the method, a source/drain region is formed before growth of an epitaxial layer. At this point, by forming the source/drain region in a state that a trench has been formed by etching a substrate, the source/drain region is sufficiently deep, and the overlap between the side of the source/drain region and a gate pattern is reduced, leading to improving a leakage current characteristic of the transistor and preventing a short channel effect.

In accordance with an aspect of the present invention, there is provided a method of fabricating a transistor for use in a semiconductor device. The method includes forming a gate structure over a substrate, forming a first trench by etching the substrate on either side of the gate structure to a first depth, ion-implanting dopants of a first conductivity type to form a source/drain region in the substrate on the side of the gate structure with the first trench, etching the substrate on the side of the gate structure with the first trench to a second depth larger than the first depth to form a second trench, and growing an epitaxial layer within the second trench.

In accordance with another aspect of the present invention, there is provided a method of fabricating a transistor for use in a semiconductor device. The method including: forming a first trench by etching a substrate on a side of a gate structure to a first depth, forming a material layer over the resulting substrate structure, etching the material layer to partially expose the substrate covered by the material layer and leave a continuous layer of the material spacer over a sidewall of the gate structure and an area of the first trench, and after forming a source/drain region underneath the first trench, etching the substrate underneath the first trench to a second depth larger than the first depth to form a second trench.

In accordance with another aspect of the present invention, there is provided a method of fabricating a transistor for use in a semiconductor device. The method including: forming an isolation layer defining an active region on a substrate, forming a gate structure over the substrate having the isolation layer, etching a portion of the active region between the gate structure and the isolation layer to form a first trench to a first depth, forming a material layer over the resulting substrate structure, etching the material layer to partially expose the substrate covered by the material layer and leave a discontinuous layer of the material spacer over a sidewall of the gate structure and a sidewall of the isolation layer, and after forming a source/drain region underneath the first trench, etching

the substrate underneath the first trench to a second depth larger than the first depth to form a second trench.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A to 1E are cross-sectional views explaining a structure of a conventional PMOS transistor and a fabrication method thereof.

FIGS. 2A to 2H are cross-sectional views describing a method of fabricating a transistor for use in a semiconductor device in accordance with an embodiment of the present invention.

DESCRIPTION OF SPECIFIC EMBODIMENTS

Other objects and advantages of the present invention can be understood by the following description, and become apparent with reference to the embodiments of the present invention.

Referring to the drawings, the illustrated thickness of layers and regions are exemplary only and may not be exact. When a first layer is referred to as being “on” a second layer or “on” a substrate, it could mean that the first layer is formed directly on the second layer or the substrate, or it could also mean that a third layer may exist between the first layer and the substrate. Furthermore, the same or like reference numerals represent the same or like constituent elements, although they appear in different embodiments or drawings of the present invention.

FIGS. 2A to 2H are cross-sectional views describing a method of fabricating a transistor in accordance with an embodiment of the present invention. In particular, a method of fabricating a PMOS transistor using epitaxial growth is illustrated in FIGS. 2A to 2H.

Referring to FIG. 2A, a device isolation layer **21** is formed on a substrate **20** to define an active region.

A gate pattern **22** having a stacked structure of a gate insulation layer, a gate electrode and a gate hard mask is formed on the substrate **20**, and a gate spacer **23** is formed on a sidewall of the gate pattern **22**.

Referring to FIG. 2B, the substrate **20** on either side of the gate spacer **23** is etched to a first depth **D1** to form a first trench **T1**. The first depth **D1** may be in a range from about 50 Å to about 500 Å. Reference numeral **21A** represents an etched device isolation layer.

The first trench **T1** is formed for a subsequent source/drain region, whereas the trench **T** of the prior art is formed for growth of the epitaxial layer. The formation of the first trench **T1** aims to improving leakage current characteristic caused by possible interface defect between the substrate **20** and a subsequent epitaxial layer by making the subsequent source/drain region sufficiently deep, which will be described later in detail.

Referring to FIGS. 2C and 2D, a material layer **24** is formed over a resulting structure where the gate pattern **22**, the gate spacer **23** and the first trench **T1** are formed, and the material layer **24** is anisotropically etched to form a material spacer **24A** on a sidewall of the first trench **T1** and/or a sidewall of the gate spacer **23**.

The material spacer **24A** is additionally formed in order to reduce the penetration of the dopants under the gate pattern **22** after being diffused laterally when forming the subsequent source/drain region. This process may be omitted. The material spacer **24A** may be formed of nitride.

Referring to FIG. 2E, a source/drain region **25** is formed by ion-implanting P-type dopants such as boron (B) and performing a thermal treatment such as rapid thermal annealing (RTA) for dopant activation.

As described above, since the dopant ion-implantation for formation of the source/drain region **25** and the thermal treatment are performed on the substrate **20** where the first trench **T1** is already formed, the source/drain region is sufficiently deeper than the channel region, leading to improved leakage current characteristic.

In the prior art, the source/drain region **15** is formed after an uneven epitaxial layer is grown. However, in accordance with the embodiment of the present invention, the source/drain region **25** is formed, before the growth of the epitaxial layer, within the substrate **20** where the first trench **T1** having a uniform depth is formed. Thus, compared with the prior art, the side of the source/drain region **25** penetrates, to a lesser extent, under the gate pattern **22**. That is, the overlap between the gate pattern **22** and the source/drain region **25** is reduced. Therefore, a short channel margin of the transistor is improved, and in particular, DIBL is improved.

Referring to FIG. 2F, a remaining material spacer **24A** is removed, and a counter doping region **26** is formed on the surface of the source/drain region **25** by performing a counter doping to tilted-ion-implant N-type dopants such as arsenic (As).

The process of forming the counter doping region **26** on the surface of the source/drain region **25** may be omitted.

Referring to FIG. 2G, the substrate **20** on either side of the gate spacer **23**, where the first trench **T1** is formed, is etched to a second depth **D2** to form a second trench **T2** deeper than the first trench **T1**. The second depth **D2** may be in a range from about 100 Å to about 1,000 Å, which is greater than the value of the first depth **D1**. Reference numerals **25A** and **26A** represent an etched side of the source-drain region and an etched counter doping region, respectively.

The second trench **T2** is formed for growth of a subsequent epitaxial layer.

Referring to FIG. 2H, an epitaxial layer **27** is formed within the second trench **T2** by using a sidewall and/or bottom of the second trench **T2** as a seed layer. At this point, P-type impurities (for example, boron) for forming the etched source/drain region **25A** are doped in-situ during the growth of the epitaxial layer **27**.

The epitaxial layer **27** is used to apply a stress to the channel region of the substrate **20**. In the case of the PMOS transistor, a compression stress is applied in a direction parallel to the channel region in order to increase the mobility of majority carriers, i.e., holes. Thus, the epitaxial layer **27** is formed of a material having a larger lattice constant than the substrate **20**. For example, when the substrate **20** is a Si substrate, the epitaxial layer **27** may be a SiGe epitaxial layer.

Through the processes of FIGS. 2A to 2H, the overlap between the side of the source/drain region **25** and the gate pattern **22** is reduced while making the bottom of the source/drain region **25** sufficiently deep, thus improving leakage current characteristic of the transistor and preventing a short channel effect.

In the method of fabricating the transistor for use in the semiconductor device in accordance with the embodiment of the present invention, the source/drain region is formed before growth of the epitaxial layer. At this point, by forming the source/drain region in a state that the trench has been formed by etching the substrate, the source/drain region is sufficiently deep, and the overlap between the side of the source/drain region and the gate pattern is reduced, leading to

5

improving the leakage current characteristic of the transistor and preventing the short channel effect.

While the present invention has been described with respect to the specific embodiments, it will be apparent to those skilled in the art that various changes and modifications may be made without departing from the spirit and scope of the invention as defined in the following claims.

What is claimed is:

1. A method of fabricating a transistor in a semiconductor device, the method comprising:

forming a gate structure over a semiconductor substrate;
forming a first trench by etching the semiconductor substrate on a side of the gate structure to a first depth;

ion-implanting dopants of a first conductivity type to form a source/drain region in the semiconductor substrate on the side of the gate structure with the first trench;

after forming the source/drain region, tilted-ion-implanting dopants of a second conductivity type different from the first conductivity type to form a counter doping region over the surface of the source/drain region;

etching the semiconductor substrate on the side of the gate structure with the first trench to a second depth larger than the first depth to form a second trench, wherein the source/drain region remains under the second trench after the etching of the semiconductor substrate to form the second trench; and

growing an epitaxial layer within the second trench.

6

2. The method of claim 1, further comprising, after forming the first trench:

forming a material layer over a resulting structure; and anisotropically etching the material layer to form a material spacer in the trench and on a sidewall of the gate structure.

3. The method of claim 2, wherein the material spacer comprises a nitride layer.

4. The method of claim 1, wherein the transistor is a PMOS transistor, and the first conductivity type is a P-type.

5. The method of claim 1, wherein the transistor is a PMOS transistor, and the first conductivity type and the second conductivity are a P-type and an N-type, respectively.

6. The method of claim 1, wherein the semiconductor substrate comprises a Si substrate and the epitaxial layer comprises a SiGe epitaxial layer.

7. The method of claim 1, wherein forming the source/drain region comprises performing a thermal treatment after the ion implantation of the dopants of the first conductivity type.

8. The method of claim 1, wherein the dopants of the first conductivity type are doped in-situ while growing the epitaxial layer.

9. The method of claim 1, wherein the source/drain region remains under a bottom surface of the second trench after the etching of the semiconductor substrate to form the second trench.

* * * * *